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Transcutaneous monitoring of blood gases: is it comparable with arterialized earlobe sampling?

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Researchers are increasingly looking for reliable non-invasive methods of assessing blood gas concentrations, and several new techniques have recently become available. Values derived using arterialized earlobe samples have been found to be comparable with conventional arterial samples, and recent studies have compared transcutaneous blood gas analysis with the traditional arterial samples and found a reasonable level of agreement in particular for the partial pressure of carbon dioxide. There are no data comparing oxygen and carbon dioxide partial pressures (pO_2, pCO_2) derived from arterialized samples with one of the newer transcutaneous techniques. We therefore simultaneously studied arterialized earlobe blood gas samples and values for pO_2 and pCO_2 obtained by a transcutaneous monitor (TINA, Radiometer, Copenhagen) in 26 subjects with varying blood gas values. There was a close agreement between the two methods for assessment of pCO_2 [mean difference (95% C.I.) between transcutaneous and earlobe values 0·25 kPa (−0·004, 0·5 kPa)], but not for pO_2 [1·71 kPa (0·35, 3·07 kPa)]. Similarly, the limits of agreement were narrow for pCO_2 compared to those for pO_2 (−0·98, 1·47 kPa and −6·44, 3·02 kPa respectively). We conclude that transcutaneous measurement of pCO_2 using the TINA is acceptable in the research setting, whereas assessment of pO_2 cannot reliably be made using this technique.

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Introduction

Researchers are increasingly looking for reliable non-invasive techniques to broaden the population they can reasonably study. As the role of carbon dioxide partial pressure (pCO_2) on the modulation of many physiological systems is increasingly realized it is necessary to find ways to measure this easily and reliably for the duration of the study period, which may be several hours, and in a way acceptable to the subject. We have, therefore, looked at different methods for the continuous measurement of blood gas tensions.

Traditionally blood gas analysis has involved arterial punctures either repeatedly performed or drawn from an indwelling arterial catheter. Both of these techniques can be distressing to the patient, and are not without associated complications (1–4). Arterialized earlobe blood samples are now more commonly used, and studies have found a good agreement between this technique and radial artery samples, especially for pCO_2, although, there is dispute over its accuracy for measuring oxygen tension (pO_2) (5–7). Some of these differences can be explained by technical discrepancies, in particular the degree of arterialization of the earlobe blood, and repetitive sampling can further adversely affect this.

Since the late 1950s electrodes that can assess O_2 and CO_2 transcutaneously have been developed (8). More recently a combined sensor has been developed by Radiometer (9) using both a Clark-type electrode and a Severinghaus-type electrode housed in the same casing to calculate pO_2 and pCO_2 respectively, the results of which are digitally displayed. A number of studies have compared the results of this and arterial samples [10–15). However, there are statistical criticisms with many of them, since they use correlation coefficients and regression plots to assess the agreement, therefore making differences between the techniques (i.e. bias) difficult to interpret. Sridhar *et al.* (10), however, do use the statistical methods recommended by Bland and Altman for comparing two methods of clinical measurement (16), and found that agreement was again better for pCO_2 than pO_2.

To our knowledge there have been no comparisons of transcutaneous and arterialized methods. We, therefore, report a study comparing arterialized earlobe blood samples and a transcutaneous pO_2–pCO_2 monitoring system (TINA, Radiometer, Copenhagen).

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Methods

Twenty-six subjects (14 female) were studied; ten were healthy volunteers recruited from the hospital staff, and the others were patients attending the respiratory physiology department for routine assessment of earlobe blood gases.

Subjects were asked to remove earrings if necessary, and 'Algipan' (a topical ointment containing capsicic, glycol salicylate and methyl nicotinate) was liberally applied to their left earlobe and massaged in to promote local vasodilatation and increased arterialization of the blood. The transcutaneous monitor was applied using a similar method to that reported in previous studies (10,11,13,14). The subjects were sat upright in a chair and a small area at the top of their chest was cleaned with an alcohol wipe, and if necessary shaved, to enable a custom-made adhesive electrode holder for the TINA to be attached to their skin. A few drops of electrode fluid were then placed in the holder before the electrode was fixed in place and supported by a clip from the subjects clothing. The electrode had previously been calibrated off-line with a standard calibration gas of 5% CO_2 and 20·9% O_2, with adjustments for the barometric pressure being made, and its temperature was set at 45°C to promote local skin vasodilatation. The electrode was then left to equilibrate over the next 5 min.

A pulse oximeter was simultaneously applied to a finger on the dominant hand to measure SaO_2. After 5 min the earlobe was cleaned and incised with a sterile scalpel blade, and the arterialized blood was taken up by a heparinized capillary tube and then analysed using a Ciba-Corning (Essex, U.K.) 280M blood gas analyser. Simultaneously the results of pulse oximetry and the TINA were noted.

All subjects had given informed consent to the investigation.

Statistical Analysis

Statistical analysis was performed using the Minitab 10 statistical computer package.

Results are presented as mean ± SD. The differences between the two methods are described as mean (95% CI) and also were assessed using Student's paired t test, together with limits of agreement as described by Bland and Altman. Scatter plots and Bland–Altman plots are also shown. Regression analysis was performed to see whether any independent factor (e.g. age, arterial pO_2), influenced these results.

Results

Ten healthy volunteers and 16 patients (14 female) with a mean age of 49·7 ± 14·3 years (range 27–71 years), and a variety of respiratory complaints were studied. The mean values of arterialized and transcutaneous pCO_2 and pO_2, along with oximetry results are given in Table 1. On earlobe blood gas values three subjects were hypercapnic (normal range 4·8–6·1 kPa), and ten subjects were hypoxic (normal range 10–13·3 kPa).

TABLE 1. Baseline characteristics presented as mean ± standard deviation

Variable	Mean ± SD
No. of subjects	26 (14 F)
Age	49·7 ± 14·3 years
Earlobe pCO_2	5·2 ± 0·8 kPa
TINA PCO_2	5·5 ± 1·2 kPa
Earlobe pO_2	10·6 ± 2·1 kPa
TINA pO_2	8·8 ± 2·3 kPa
Pulse oximeter	95·8% ± 3·8%
Earlobe SaO_2	95·1% ± 3·3%

The pO_2 values from the two techniques were significantly different (P=0·001), with the TINA underestimating pO_2 (mean difference 1·71 kPa, 95% CI 0·35, 3·07 kPa) and wide limits of agreement (−6·44, 3·02 kPa). The difference between the pCO_2 readings was non-significant (P>0·05), although the TINA tended to overestimate the pCO_2 result (mean difference 0·25 kPa, 95% CI −0·004, 0·5 kPa), and the limits of agreement were narrow (−0·98, 1·47 kPa). Oximetry results were similarly not significantly different (mean difference oximetry 0·72%, 95% CI −0·001%, 1·45%), with narrow limits of agreement (−2·84%, 4·28%). These results are presented graphically in Fig. 1 as Bland–Altman plots.

On multiple regression analysis none of the independent variables entered, i.e. age, gender, earlobe pCO_2 or pO_2, pH, haemoglobin or bicarbonate concentration, was an independent predictor for the between-method differences. As expected CO_2, pH and bicarbonate were significantly related, and there was a non-significant trend towards an inverse relation between pCO_2 and pO_2, which again was not unexpected in view of the case mix of subjects.

Discussion

We report here a comparison between the TINA transcutaneous blood gas analyser and arterialized earlobe blood gas sampling and demonstrate a non-significant difference and narrow limits of agreement for pCO_2 measurement between the two techniques, although there is a bias towards an overestimation with the TINA which must be considered. As in most studies comparing different methodologies we attempted to study a subject group with a wide spectrum of blood gas results, but our group did only contain a few people with pCO_2 levels in the hypercapnoeic range (determined by arterialized earlobe sampling), so we cannot confidently say how reliable this method is for these patients, although these subjects did not appear to skew our results. However, our results do not indicate that this technique is acceptable for the measurement of pO_2, with the two methods being significantly different (P=0·001) and the transcutaneous readings being much lower regardless of whether the earlobe values were in the normal or hypoxic range. As expected there was no significant difference

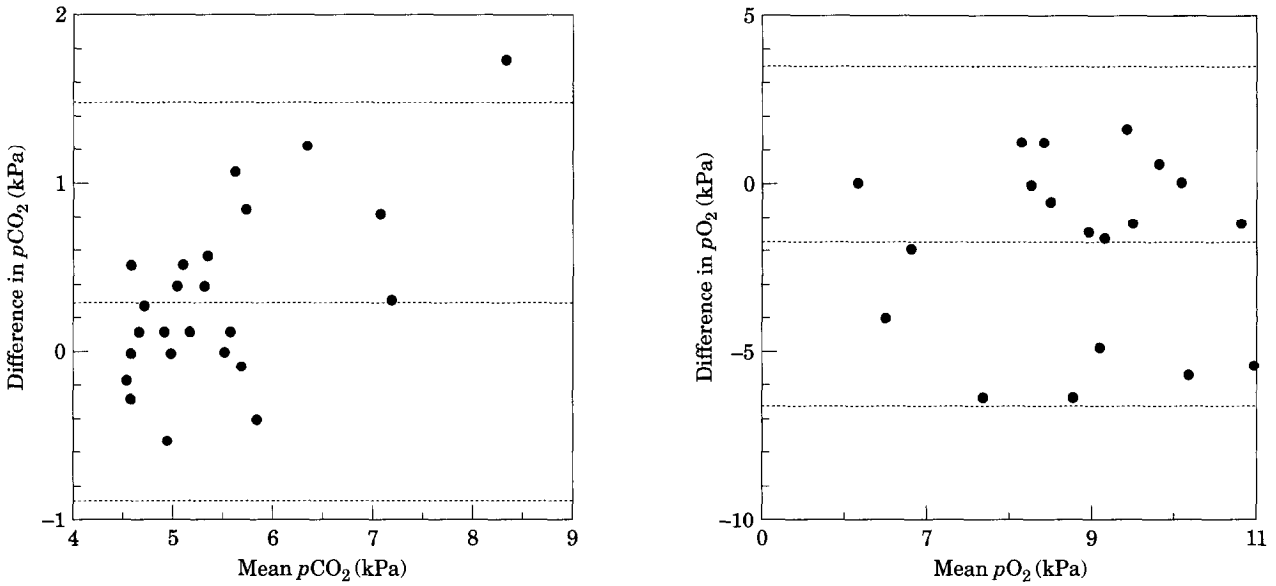

FIG. 1. Bland–Altman plots of pCO_2 and pO_2 obtained by the transcutaneous and earlobe methods with mean difference and limits of agreement shown.

between arterialized earlobe sampling oxygen saturation levels and those measured by the traditional non-invasive pulse oximeter.

Previous studies (5–7) have compared arterial and arterialized sampling and found mean differences for pCO_2 from 0·07 to 0·21 kPa, which are comparable with the results we present here, although the results for pO_2 are very different with mean differences of only −0·17 to 0·59 kPa. Sauty *et al.* (7), who found the poorer correlation for O_2, felt that this was due to insufficient arterialization of the earlobe, and with this in mind our Respiratory Physiology Department proceeds to arterial sampling if there is a greater than 2% difference between the saturation of the earlobe sample and a simultaneous pulse oximetry measurement.

Sridhar *et al.* (10) compared arterial and transcutaneous measurements using a transcutaneous technique very similar to the one adopted in this study and found that the mean difference for pCO_2 was 0·02 kPa and for pO_2 0·08 kPa. They too showed a bias towards an underestimation of pO_2 with the transcutaneous monitor. However, others have found, as we have, less good agreement for pO_2 and the same bias, especially in situations of low capillary perfusion (11,13,14), e.g. Mahutte *et al.* (14) show a linear regression coefficient of only 0·57 between the two methods for pO_2 assessment.

Some of the differences between our results and those of the other investigators mentioned here may have been improved by technical changes, in particular to the skin preparation. Dermatological studies (17) have shown that skin thickness, stratum corneum barrier function and damage, blood vessel reactivity, arterial gas concentration, and skin and environmental temperature all influence transcutaneous gas flux. Others have shown the importance of temperature and posture especially in patients with peripheral vascular disease(18). Better skin preparation with application of a vasodilator such as 'Algipan', plus more aggressive cleaning with an alcohol wipe to disrupt the stratum corneum, together with a longer run-in period to increase the local heating effect of the probe would probably improve the results for pO_2.

In conclusion, the TINA is a reliable non-invasive method for the assessment of pCO_2. However, because its response time is at least 5 min (according to Radiometer), it is not suitable for studies where significant or transient changes in pCO_2 are expected and need detecting. The results of this study do not support the use of this machine for assessing pO_2 until technical details are improved and standardised.

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